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Dual-Channel Supply Chain Coordination Considering the Consumer's Perception of Quality

Abstract. *This paper examines a dual-channel supply chain that sells the identical products in two channels. Consumers have a higher perception of product quality in the offline channel. Based on the solving and comparing of game models, the residual profit-sharing contract with decentralised supply chain cost payment (coordination contract 1) and the residual profit-sharing contract with decentralised supply chain profit allocation (coordination contract 2) are designed for the dual-channel supply chain coordination. The results show that the centralised supply chain can provide higher quality products and gain more profits. The high quality perception of consumers is beneficial to all supply chain members. Two coordination contracts can achieve coordination and allow the supply chain members to gain relatively fair profits. Under these two contracts, the consumer's perception of quality can positively affect the members' profits. The results will provide the dual-channel supply chain members with solutions for channel coordination and profit expansion.*

Keywords: *coordination, dual-channel supply chain, perception of quality, decision model.*

JEL Classification: C63, C70, D40.

1. Introduction

The buying habits of consumers have drastically changed due to the rapid rise of e-commerce (Yan et al., 2022). Consumers online purchase a wide variety of goods, including food, wine, clothing, bags, skin care products, furniture, home appliances, etc. In this context, many manufacturers sell products directly online to consumers through e-commerce platforms, while wholesale their products to retailers in the offline retail channel. For example, Huawei, a leading Chinese cell phone manufacturer, sells its phones directly to consumers through Taobao, in addition to wholesaling them to retailers. Dual-channel supply chains, where manufacturers sell their products in both online and offline channels, have become the most widespread supply chain in modern society.

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Product quality and price are the two most critical factors that influence a consumer's purchase decision to buy a product (Erkoc et al., 2023). In one consumer survey, more than 60% of consumers agree with the above views (Deloitte, 2023). Therefore, members require rational quality and pricing decisions to improve consumer demands and gain more profits in the dual-channel supply chain. Numerous scholars have studied the dual-channel supply chain's optimal quality and pricing decisions (Hu et al., 2019; Zhang et al., 2020). However, there is a fact that they overlooked. That is, consumers often have different perceptions of quality for the identical products from different channels. Consumers' perception of product quality reflects their psychological evaluation of product quality (Fu et al., 2021). Thus, it is meaningful to research the dual-channel supply chain, where consumers' perception of product quality in the two channels varied.

Meanwhile, conflicts and competition between manufacturers and retailers are inevitable in dual-channel supply chains (Zhang et al., 2020). On the one hand, it is because the online channels opened by manufacturers captured the potential market for retailers. On the other hand, it is because manufacturers and retailers will compete on price to increase their own consumer demand. The competition between the two sides ultimately caused a negative impact on the supply chain performance. Coordination contracts provide means to eliminate the negative impact. Contracts such as cost-sharing, profit-sharing, and combinations of these contracts have been used to coordinate dual-channel supply chains (Ke et al., 2021; Liu et al., 2022; Hu et al., 2020; Zhu et al., 2020). Although these contracts can achieve coordination goals, they often fail to achieve an equitable distribution of profits. The reason is that the distribution of profits under these contracts often depends on the dual-channel supply chain members' bargaining power (Zhu et al., 2020). Therefore, it is very critical to design relatively fair coordination contracts.

Therefore, this paper examines the dual-channel supply chain where consumers have varied perceptions of quality between the offline and online channels. The centralised supply chain and decentralised supply chain are analysed and compared based on game theory. A residual profit-sharing contract with decentralised supply chain cost payment (coordination contract 1) and a residual profit-sharing contract with decentralised supply chain profit allocation (coordination contract 2) are designed for the dual-channel supply chain coordination. These two coordination contracts can achieve the relatively fair profit distribution.

The remainder of this paper is as follows. Section 2 reviews the existing literature. The model is described and developed in Section 3. Section 4 solves and compares the decision models. Two coordination contracts are proposed in Section 5. Section 6 performs numerical simulations and discusses. The conclusion is given in Section 7.

2. Literature Review

2.1 Product quality in the supply chain

Product quality, which can greatly affect the consumer market, has received widespread attention. Atasu and Souza (2013) defined quality as a performance indicator that can improve the product value. In supply chain decisions and coordination studies, scholars have mainly focused on product quality as a decision variable. For example, Gurnani et al. (2007) and Ha et al. (2016) developed game models to analyse the optimal quality decisions under different power structures. Ebrahimi et al. (2022) focused on a sustainable supply chain where manufacturers make quality effort decisions. In the field of dual-channel supply chain, Chen et al. (2017) obtained pricing and quality of products decisions in a dual-channel supply chain. Zhang et al. (2020) found that the pursuit of low return rates of defective products through costly quality improvements would be detrimental to performance. Some scholars take the supply chain quality issue as a background to conduct research. For instance, Erkoc et al. (2023) investigated the issue of supply chain quality investment under different quality inspection policies and found that lower input quality motivates higher inspections and leads to higher final product quality. Giri and Dey (2023) investigated the coordination problem under uncertainty of recycled product quality.

The mentioned research restricts to the product quality level and has not taken into account the consumer's perceived quality. The consumer's perceived quality refers to the consumer's subjective ability to judge the product quality level (Zeithaml, 1988). Mitra and Golder (2006) found that consumers' product perceived quality is a determining factor that influences consumer satisfaction. That is, consumers' purchase decisions depend on the product's perceived quality rather than the unobservable real quality. Therefore, several scholars have studied consumer perceived quality in supply chains. Liu et al. (2016) focused on the expected perceived reference quality of consumers and investigated the impact of short-sighted and far-sighted behaviour on product quality decisions. Fu et al. (2021) developed a demand function on perceived quality to obtain optimal pricing, quality, and packaging decisions. Chen et al. (2022) considered the consumer's perceived green quality and found that limited subsidies under government utility orientation could enhance product green quality.

The literature mentioned has extensively investigated product quality in supply chains. However, little literature studies the consumer's quality perceptions in dual-channel supply chains. The consumer's perception of quality always differs between the offline and online channels. This reality requires more attention. Therefore, starting from the reality, this paper established and solved two decision models in which the consumer's quality perceptions are different between online and offline channels.

2.2 Coordination of dual-channel supply chains

Over the past decade, dual-channel supply chain coordination has been a hot research topic in academia. Scholars have used extensive contracts to pursue the coordination. These contracts include cost-sharing contract (Liu et al., 2022), two-part tariff contract (Hu et al., 2022), profit-sharing contract (Hu et al., 2020), etc. or combinations and improvements of these contracts. For instance, Xie et al. (2017) and Zhang et al. (2020) used a profit-sharing contract to complete the coordination of dual-channel closed-loop supply chain. A reasonable profit-sharing ratio was determined to redistribute members' profits. Xu et al. (2022) proposed a supplier profit-sharing contract to realise optimal performance. Chen et al. (2012) used a combination of wholesale price and two-part tariff contracts, and a combination of wholesale price and profit-sharing contracts for coordination. Xu et al. (2014) used a bidirectional revenue sharing contract to achieve coordination under risk aversion. Ranjan and Jha (2019) proposed a residual profit-sharing mechanism.

Although coordination can be achieved with the above contracts, the profits of manufacturers and retailers often depend on the bargaining power of both parties (Xu et al., 2022; Chen et al., 2012; Xu et al., 2014; Ranjan and Jha, 2019). These contracts fail to achieve coordination with relative fairness. In this paper, based on the research of Ranjan and Jha (2019), coordination contract 1 and coordination contract 2 are designed. Under the two contracts, both parties' profits are based on their own cost payments or profit allocations under the decentralised supply chain. Therefore, relative fairness can be achieved under these two contracts.

In conclusion, the following are the novelties of this paper: (1) This paper considers the situation where consumer quality perceptions are different between offline and online channels. Based on previous studies, a demand function that considers the consumer's perception of quality is established, and the optimal decisions and profits are analysed. (2) Two new contracts are developed to coordinate the dual-channel supply chain. These two contracts can achieve relative fairness of members' profits.

3. Model Description

3.1 Problem Description

This paper investigates a dual-channel supply chain composed of a manufacturer, a retailer, and consumers. The manufacturer produces products with a quality level q and sells them through two sales channels. The products in both channels are exactly the same. The first sales channel is an online channel where the manufacturer directly sells products to consumers with a direct selling price p_m. The second sales channel is an offline channel where the manufacturer sells products to the retailer with a wholesale price ω . After wholesale products from the manufacturer, the retailer sells products to consumers at a retail price p_r. Consumers can purchase products from two channels according to their own channel preferences, and have different perceptions of product quality in the two channels.

3.2 Notations Explanation

The relevant notations are described as follows.

(1) Decision variables: ω – wholesale price; p_r – offline retail price, $p_r > \omega$; p_m – online direct selling price, $p_m > \omega$; q – quality level.

(2) Model parameters: d – basic market demand, $d > 0$; ρ – market share of the offline retail channel, $0 < \rho < 1$; β – cross price elasticity coefficient, $0 < \beta < 1$; γ – quality sensitivity coefficient, $0 < \gamma < 1$; μ_1 – consumer perception coefficient of product quality in the offline retail channel, $0 < \mu_1 < 1$; μ_2 – consumer perception coefficient of product quality in the online direct sales channel, $0 < \mu_2 < 1$; k – quality investment cost coefficient, $k > 0$.

(3) Other notations: Q_r – consumer demand in the offline retail channel, $Q_r > 0$; Q_m – consumer demand in the online direct sales channel, $Q_m > 0$; T – quality cost; π_m – manufacturer's profit; π_r – retailer's profit; π_{sc} – supply chain's profit.

3.3 Assumptions

(1) Consumers can only purchase products from the retailer (offline retail channel) or from the manufacturer (online direct sales channel).

(2) Consumers consider both price and quality level when they purchase products.

(3) When consumers purchase products in the offline channel, they could truly feel the product quality through the explanation of the salesperson and touching the physical products. As a result, consumers perceive higher product quality in the offline channel. That is, $\mu_2 < \mu_1$.

(4) Consumers' product perceived quality is the multiplication of the quality perception coefficient and the real quality. Therefore, consumers' product perceived quality in offline and online channels is $\mu_1 q$ and $\mu_2 q$, respectively.

(5) Supply chain members are perfectly rational economic agents.

(6) The manufacturer's cost includes two components: marginal manufacturing cost and quality cost. The marginal manufacturing cost of products is assumed to be 0.

3.4 Model Construction

The consumer demand function is a linear function of price and perceived quality level, which is an extension of previous studies (Erkoc et al., 2023; Zhang et al., 2020). The demand for a channel is negatively impacted by the sales price of its own channel, and positively impacted by the sales price of another channel and perceived quality level of products. The consumer demand function for online and offline channels can be expressed separately as: $Q_r = \rho d - p_r + \beta p_m + \gamma(\mu_1 q)$;

$Q_m = (1-\rho)d - p_m + \beta p_r + \gamma(\mu_2 q)$. Moreover, referring to previous studies (Erkoc et al., 2023; Chen et al., 2017), the manufacturer's quality cost can be expressed as: $T = \frac{1}{2}kq^2$.

Therefore, the manufacturer's profit function can be expressed as:

$$\pi_m = p_m Q_m + \omega Q_r - T = p_m[(1-\rho)d - p_m + \beta p_r + \gamma(\mu_2 q)] + \omega[\rho d - p_r + \beta p_m + \gamma(\mu_1 q)] - \frac{1}{2}kq^2 \quad (1)$$

The retailer's profit function is:

$$\pi_r = (p_r - \omega)Q_r = (p_r - \omega)[\rho d - p_r + \beta p_m + \gamma(\mu_1 q)] \quad (2)$$

The dual-channel supply chain's profit function is:

$$\pi_{sc} = \pi_m + \pi_r = p_m[(1-\rho)d - p_m + \beta p_r + \gamma(\mu_2 q)] + p_r[\rho d - p_r + \beta p_m + \gamma(\mu_1 q)] - \frac{1}{2}kq^2 \quad (3)$$

4. Decision Model Analysis

4.1 Centralised Supply Chain Decision Model

In this scenario, members pursue the overall profit optimisation. The manufacturer and retailer make decisions from a holistic perspective. They maximise the supply chain's profit by determining the retail price, direct selling price, and quality level. The decision target function is shown in Equation 3. The superscript *c* denotes the equilibrium under the centralised supply chain decision model. The equilibrium results under the centralised supply chain decision model are shown in Table 1.

Table 1. The equilibrium results under decision models

	centralised supply chain (c)	decentralised supply chain (s)
p_r	$\frac{d(\rho\gamma^2{\mu_2}^2+2kB_1+C\gamma^2\mu_1\mu_2)}{2A}$	$\frac{d[2k(\beta^2\rho-\rho+2B_1)+\gamma^2(2\beta\mu_1+3\mu_2)(C\mu_1+\rho\mu_2)]}{4D}$
p_m	$\frac{d(2kB_2+C\gamma^2{\mu_1}^2+\gamma^2\rho\mu_1\mu_2)}{-2A}$	$\frac{d(4kB_2+\gamma^2C{\mu_1}^2+\gamma^2\rho\mu_1\mu_2)}{-4D}$
q	$\frac{\gamma d(\mu_1B_1-\mu_2B_2)}{A}$	$\frac{\gamma d[\mu_1(\beta B_2-B_1)+2B_2\mu_2]}{-2D}$
ω	—	$\frac{d[4kB_1+\gamma^2(C\mu_1+\rho\mu_2)(\beta\mu_1+2\mu_2)]}{4D}$
π_m	—	$\frac{d^2[2k\rho^2(\beta^2-1)+\gamma^2[\rho^2(\mu_1+\mu_2)^2-(2C+1){\mu_1}^2-2\rho\mu_1\mu_2]-4k{B_2}^2]}{8D}$
π_r	—	$\frac{d^2[C\mu_1(\beta\mu_1+\mu_2)\gamma^2+\rho E]^2}{16D^2}$
π_{sc}	$\frac{d^2\begin{bmatrix}4k\rho(B_1+1)+\\ \gamma^2(C\mu_1+\rho\mu_2)^2-2k\end{bmatrix}}{4A}$	$\frac{d^2\begin{Bmatrix}[C\mu_1(\beta\mu_1+\mu_2)\gamma^2+\rho E]^2+2D[2k\rho^2(\beta^2-1)-4k{B_2}^2]\\ +2D\gamma^2[\rho^2(\mu_1+\mu_2)^2-(2C+1){\mu_1}^2-2\rho\mu_1\mu_2]\end{Bmatrix}}{16D^2}$

Source: Authors' own creation.

Where, $A = 2\beta^2 k + 2\beta\gamma^2\mu_1\mu_2 + \gamma^2{\mu_1}^2 + \gamma^2{\mu_2}^2 - 2k < 0$, $B_1 = \beta\rho - \rho - \beta < 0$, $B_2 = \beta\rho - \rho + 1 > 0$, $C = \rho - 1 < 0$, $D = 2\beta^2 k - 2k + \frac{1}{2}\gamma^2\beta^2{\mu_1}^2 + \frac{1}{2}\gamma^2{\mu_1}^2 + 2\gamma^2\beta\mu_1\mu_2 + \gamma^2{\mu_2}^2 < 0$, $E = 2\beta^2 k + \gamma^2\beta\mu_1\mu_2 + \gamma^2{\mu_2}^2 - 2k < 0$.

The solution process of the centralised supply chain decision model: According to Equation 3, the Hessian matrix of π_{sc} about p_r, p_m, and q as:

$$\begin{bmatrix} -2 & 2\beta & \gamma\mu_2 \\ 2\beta & -2 & \gamma\mu_1 \\ \gamma\mu_2 & \gamma\mu_1 & -k \end{bmatrix}$$

We can obtain that $\Delta1 = -2 < 0$, $\Delta2 = 4 - 4\beta^2$, and $\Delta3 = 4\beta^2 k + 4\beta\gamma^2\mu_1\mu_2 + 2\gamma^2{\mu_1}^2 + 2\gamma^2{\mu_2}^2 - 4k$. Because $0 < \beta < 1$, we can get $\Delta2 > 0$. Therefore, when $\Delta3 < 0$ ($k > k_1 = \frac{\gamma^2({\mu_1}^2 + {\mu_2}^2 + 2\beta\mu_1\mu_2)}{2(1-\beta^2)}$), there are optimal p_r, p_m, and q to maximise π_{sc}. Make $\frac{\partial\pi_{sc}}{\partial p_r} = 0$, $\frac{\partial\pi_{sc}}{\partial p_m} = 0$, and $\frac{\partial\pi_{sc}}{\partial q} = 0$, ${p_r}^c$, ${p_m}^c$, and q^c could be derived as shown in Table 1. Therefore, ${\pi_{sc}}^c$ can be derived as seen in Table 1.

4.2 Decentralised Supply Chain Decision Model

In this scenario, both parties paly the Stackelberg game and pursue their own profit optimisation. The manufacturer first decides the wholesale price ω, the online direct selling price p_m and the quality level q. The decision target function can be seen in Equation 1. The retailer then decides the offline retail price p_r. The decision target function can be seen in Equation 2. Backward induction is used to solve for equilibrium results. The superscript s denotes the equilibrium under the decentralised supply chain decision model. The equilibrium results under the decentralised supply chain decision model are shown in Table 1.

The solution process of the decentralised supply chain decision model: According to Equation 2, we can obtain that $\frac{d^2\pi_r}{d{p_r}^2} = -2 < 0$. Therefore, π_r is the concave function of p_r. Let $\frac{d\pi_r}{dp_r} = 0$, we can acquire:

$$ {p_r}^s = \frac{\beta p_m + d\rho + \mu_1\gamma q + \omega}{2} \quad (4)$$

Substituting Equation 4 into Equation 1, the Hessian matrix of π_m about p_m, ω, and q as:

$$\begin{bmatrix} \beta^2 - 2 & \beta & \frac{1}{2}\gamma\beta\mu_1 + \gamma\mu_2 \\ \beta & -1 & \frac{1}{2}\gamma\mu_1 \\ \frac{1}{2}\gamma\beta\mu_1 + \gamma\mu_2 & \frac{1}{2}\gamma\mu_1 & -k \end{bmatrix}$$

We can obtain that $\Delta1 = \beta^2 - 2 < 0$, $\Delta2 = 2 - 2\beta^2 > 0$, and $\Delta3 = 2\beta^2 k - 2k + \frac{1}{2}\gamma^2\beta^2{\mu_1}^2 + \frac{1}{2}\gamma^2{\mu_1}^2 + 2\beta\gamma^2\mu_1\mu_2 + \gamma^2{\mu_2}^2 < 0$. Therefore, there are optimal p_m, ω, and q to maximise π_m. Make $\frac{\partial\pi_m}{\partial p_m} = 0$, $\frac{\partial\pi_m}{\partial\omega} = 0$, and $\frac{\partial\pi_m}{\partial q} = 0$, ${p_m}^s$, ω^s, and q^s can be derived as seen in Table 1. Substituting ${p_m}^s$, ω^s, and q^s into Equation 4, we can acquire ${p_r}^s$, as seen in Table 1. Furthermore, we can obtain ${\pi_m}^s$, ${\pi_r}^s$, and ${\pi_{sc}}^s$ as shown in Table 1.

4.3 Decision model comparisons

Corollary 1: The comparative results of the quality level: $q^c > q^s$.

Proof. Using q^c to subtract q^s to get Corollary 1.

From Corollary 1, the quality level under the centralised supply chain is higher than that under the decentralised supply chain. The reason is that in centralised supply chain, the manufacturer's goal is to achieve the overall profit optimisation and to optimise quality. In a decentralised supply chain, higher product quality level will increase the manufacturer's cost. The manufacturer, as the leader, does not increase the cost to improve the quality level.

Corollary 2: The comparative results of the online direct selling price: ${p_m}^c > {p_m}^s$.

Proof. Using ${p_m}^c$ to subtract ${p_m}^s$ to get Corollary 2.

From Corollary 2, the online direct selling price under the centralised supply chain is higher than that under the decentralised supply chain. It is identical to the comparison of quality level in Corollary 1. The reason is as follows. In the centralised supply chain, a higher product quality level results in higher cost for the manufacturer. The manufacturer will increase the online direct selling price to improve online unit benefit, so as to make up for the cost input of product quality.

Corollary 3: The comparative results of the offline retail price: when $k_1 < k < k_2$, ${p_r}^c > {p_r}^s$; when $k > k_2$, ${p_r}^s > {p_r}^c$. In the above equations, $k_2 = \frac{\gamma^2(2{\mu_1}^2 + {\mu_2}^2 + 3\beta\mu_1\mu_2)}{2(1-\beta^2)}$.

Proof. Using ${p_r}^c$ to subtract ${p_r}^s$ to get Corollary 3.

It can be concluded from Corollary 3 that when the quality investment cost coefficient is smaller, the offline retail price under the centralised supply chain is greater than that under the decentralised supply chain. When the quality investment cost coefficient is higher, the comparison results are reversed. The reason is that a lower quality investment cost coefficient will reduce the quality investment cost. The product quality level in the two decision models differs significantly. The product quality cost under the two decision models also differs significantly. The higher the cost, the more the price needs to be raised to cover the cost. Therefore, the retailer determines a higher offline retail price in the centralised supply chain.

Corollary 4: The comparative results of the overall profit: ${\pi_{sc}}^c > {\pi_{sc}}^s$.

Proof. Using ${\pi_{sc}}^c$ to subtract ${\pi_{sc}}^s$ to get Corollary 4.

From Corollary 4, the overall profit under the centralised supply chain is greater than that under the decentralised supply chain. The reason is that the decision goal of supply chain members is to optimise the overall profit in the centralised supply chain. The negative impact of the double marginalisation is eliminated. Therefore, the centralised supply chain is more profitable.

4.4 Sensitivity analysis

Corollary 5: The influence of consumer perception coefficient of product quality on the centralised supply chain: (1) $\frac{\partial q^c}{\partial \mu_1} > 0$, $\frac{\partial {p_m}^c}{\partial \mu_1} > 0$, $\frac{\partial {p_r}^c}{\partial \mu_1} > 0$, $\frac{\partial {\pi_{sc}}^c}{\partial \mu_1} > 0$; (2) $\frac{\partial q^c}{\partial \mu_2} > 0$, $\frac{\partial {p_m}^c}{\partial \mu_2} > 0$, $\frac{\partial {p_r}^c}{\partial \mu_2} > 0$, $\frac{\partial {\pi_{sc}}^c}{\partial \mu_2} > 0$.

Proof. Using q^c, ${p_m}^c$, ${p_r}^c$ and ${\pi_{sc}}^c$ take the partial derivatives of μ_1 and μ_2, respectively, Corollary 5 can be obtained.

From Corollary 5, the increase in the consumer perception coefficient of product quality will cause the increase in quality, prices and supply chain's profit in centralised supply chain, whether it is consumer perception coefficient of product quality in the offline or online channels. The reason is that with the increase of the consumer's perception of product quality, consumers will have more motivation to buy products, which leads to the growth of consumer demand. Increased consumer demand brings an overall increase in profit. Supply chain members have sufficient motivation to improve quality. This makes supply chain members pay extra cost of quality improvement. Supply chain members will increase selling prices to offset increases in quality improvement costs.

Corollary 6: The influence of consumer perception coefficient of product quality on the decentralised supply chain: (1) $\frac{\partial q^s}{\partial \mu_1} > 0$, $\frac{\partial \omega^s}{\partial \mu_1} > 0$, $\frac{\partial {p_m}^s}{\partial \mu_1} > 0$, $\frac{\partial {p_r}^s}{\partial \mu_1} > 0$, $\frac{\partial {\pi_m}^s}{\partial \mu_1} > 0$, $\frac{\partial {\pi_r}^s}{\partial \mu_1} > 0$, $\frac{\partial {\pi_{sc}}^s}{\partial \mu_1} > 0$; (2) $\frac{\partial q^s}{\partial \mu_2} > 0$, $\frac{\partial \omega^s}{\partial \mu_2} > 0$, $\frac{\partial {p_m}^s}{\partial \mu_2} > 0$, $\frac{\partial {p_r}^s}{\partial \mu_2} > 0$, $\frac{\partial {\pi_m}^s}{\partial \mu_2} > 0$, $\frac{\partial {\pi_r}^s}{\partial \mu_2} > 0$, $\frac{\partial {\pi_{sc}}^s}{\partial \mu_2} > 0$.

Proof. Using q^s, ω^s, ${p_m}^s$, ${p_r}^s$, ${\pi_m}^s$, ${\pi_r}^s$ and ${\pi_{sc}}^s$ take the partial derivatives of μ_1 and μ_2, respectively, Corollary 6 can be obtained.

It can be concluded from Corollary 6 that the increase in the consumer perception coefficient of product quality will cause the increase in quality, prices, and supply chain all parties' profits in a decentralised supply chain, whether it is consumer perception coefficient of product quality in the offline or online channels. The reason is as follows. (1) With the increase of consumer's perception of quality in the offline retail channel, offline consumer demand will increase. The retailer will improve the offline retail price and can gain more profits. The increase in offline consumer demand brings more shipments for the manufacturer. Manufacturer will improve the product quality to get more demand. Increased product quality will increase the manufacturer's cost, and the manufacturer will increase the wholesale price and online direct selling price to offset the increased cost. In this process, the manufacturer's profit will increase because the positive impact of the increased consumer demand is higher than the negative impact of the increased online direct selling price and quality improvement cost. Supply chain overall profit will increase with the profits of both parties. (2) With the increase of consumer's perception of quality in the online direct sales channel, online consumer demand will increase. The manufacturer's profit rises accordingly. The manufacturer will improve product quality, and increase wholesale price and online direct selling price. The improvement of product quality also leads to the growth of offline consumer demand. The retailer's profit rise accordingly. At this point, in order not to reduce profit, the retailer will increase the offline retail price along with the wholesale price growth.

5. Coordination Contracts

Through the above analysis, we can find that the equilibrium decisions under the two decision models are different. The decentralised dual-channel supply chain profit is lower than the centralised dual-channel supply chain profit. Therefore, there is reason to coordinate the dual-channel supply chain. In the dual-channel supply chain context, Ranjan and Jha (2019) designed a residual profit-sharing contract. That is, residual profit (the profit difference between the centralised supply chain and decentralised supply chain) is distributed among supply chain members. Loblaw, a Canadian retailer, collaborated with Pollution Probe to produce and sell non-chlorine-bleached diapers through the residual profit-sharing contract (Ranjan and Jha, 2019). But the disadvantage of this contract is that the supply chain members' profit after coordination depends on their bargaining power. Fair profit distribution is especially significant for the supply chain members. When members feel unfair about profits, even if the contract could achieve coordination, they may not accept it. Therefore, inspired by Ranjan and Jha (2019), two new contracts are developed on the basis of a residual profit-sharing contract. In both contracts, members can receive relatively fair profits. The superscripts cp and pa denote the equilibrium under both contracts, respectively.

5.1 Coordination Contract 1

The detailed explanation of coordination contract 1 is as follows. Step 1: The manufacturer and the retailer form a decision-making unity and jointly determine the product quality level q, the online direct selling price p_m, and the offline retail price p_r. Step 2: When the sale is completed, the manufacturer shares the profit of $\pi_m{}^s$ and the retailer shares the profit of $\pi_r{}^s$. After that, both parties share the residual profit ($\pi_{sc}{}^{cp} - \pi_{sc}{}^s$) according to their cost payment proportions in the decentralised supply chain. The equilibrium results under the coordination contract 1 are shown in Table 2.

The solution process of the coordination contract 1: The step 1 solution procedure is the same as that of Section 4.1. We can get $p_r{}^{cp} = p_r{}^c$, $p_m{}^{cp} = p_m{}^c$, $q^{cp} = q^c$ and $\pi_{sc}{}^{cp} = \pi_{sc}{}^c$, as shown in Table 2. From Corollary 4, it follows that

${\pi_{sc}}^c > {\pi_{sc}}^s = {\pi_m}^s + {\pi_r}^s$. In the decentralised supply chain, the manufacturer's cost is $\frac{1}{2}{q^s}^2$. The retailer's cost is $\omega^s {Q_r}^s$, that is, $\omega^s(\rho d - {p_r}^s + \beta {p_m}^s + \gamma\mu_1 q^s)$. Therefore, we can get the profits of the manufacturer and the retailer in the step 2 as ${\pi_m}^{cp}$ and ${\pi_r}^{cp}$ respectively, as shown in Table 2.

Table 2. The equilibrium results under coordination contracts

	coordination contract 1 (cp)	coordination contract 2 (pa)
p_r	$\frac{d(\rho\gamma^2{\mu_2}^2+2kB_1+C\gamma^2\mu_1\mu_2)}{2A}$	$\frac{d(\rho\gamma^2{\mu_2}^2+2kB_1+C\gamma^2\mu_1\mu_2)}{2A}$
p_m	$\frac{d(2kB_2+C\gamma^2{\mu_1}^2+\gamma^2\rho\mu_1\mu_2)}{-2A}$	$\frac{d(2kB_2+C\gamma^2{\mu_1}^2+\gamma^2\rho\mu_1\mu_2)}{-2A}$
q	$\frac{\gamma d(\mu_1 B_1-\mu_2 B_2)}{A}$	$\frac{\gamma d(\mu_1 B_1-\mu_2 B_2)}{A}$
π_m	${\pi_m}^s + \frac{\frac{1}{2}{q^s}^2}{\omega^s(\rho d-{p_r}^s+\beta {p_m}^s+\gamma\mu_1 q^s)+\frac{1}{2}{q^s}^2}({\pi_{sc}}^c - {\pi_{sc}}^s)$	${\pi_m}^s + \frac{{\pi_m}^s}{{\pi_{sc}}^s}({\pi_{sc}}^c - {\pi_{sc}}^s)$
π_r	${\pi_r}^s + \frac{\omega^s(\rho d-{p_r}^s+\beta {p_m}^s+\gamma\mu_1 q^s)}{\omega^s(\rho d-{p_r}^s+\beta {p_m}^s+\gamma\mu_1 q^s)+\frac{1}{2}{q^s}^2}({\pi_{sc}}^c - {\pi_{sc}}^s)$	${\pi_r}^s + \frac{{\pi_r}^s}{{\pi_{sc}}^s}({\pi_{sc}}^c - {\pi_{sc}}^s)$
π_{sc}	$\frac{d^2[4k\rho(B_1+1)+\gamma^2(C\mu_1+\rho\mu_2)^2-2k]}{4A}$	$\frac{d^2[4k\rho(B_1+1)+\gamma^2(C\mu_1+\rho\mu_2)^2-2k]}{4A}$

Source: Authors' own creation.

Proposition 1: Coordination contract 1 can coordinate the dual-channel supply chain. The manufacturer and retailer can relatively fairly gain more profit from this coordination contract.

Proof. From the calculation, we can obtain ${\pi_m}^{cp} + {\pi_r}^{cp} = {\pi_{sc}}^c$, ${\pi_m}^{cp} > {\pi_m}^s$, and ${\pi_r}^{cp} > {\pi_r}^s$. In addition, the manufacturer and retailer can fairly share the residual profits according to decentralised supply chain cost payment ratio. This will help both parties reach the goal of allocating residual profit according to cost inputs.

5.2 Coordination Contract 2

The detailed explanation of coordination contract 2 is as follows. Step 1: The decision-making process of the supply chain members is exactly the same as that of the coordination contract 1. Step 2: When the sale is completed, the manufacturer shares the profit of ${\pi_m}^s$ and the retailer shares the profit of ${\pi_r}^s$. After that, both parties share the residual profit $({\pi_{sc}}^{cp} - {\pi_{sc}}^s)$ according to their profit allocation proportions in the decentralised supply chain. The equilibrium results under the coordination contract 2 are shown in Table 2.

The solution process of the coordination contract 2: The solution procedure is the same as that of Section 5.1.

Proposition 2: Coordination contract 2 can coordinate the dual-channel supply chain. The manufacturer and retailer can relatively fairly gain more profit from this coordination contract.

Proof. From the calculation, we can obtain ${\pi_m}^{pa} + {\pi_r}^{pa} = {\pi_{sc}}^c$, ${\pi_m}^{pa} > {\pi_m}^s$, and ${\pi_r}^{pa} > {\pi_r}^s$. In addition, the manufacturer and retailer can fairly share the residual profits according to decentralised supply chain profit allocation ratio. This will help both parties reach the goal of allocating residual profit rather by existing profit than by a column.

6. Numerical Simulations

The average monthly sales data of an infant garment from a garment company in Hebei Province, China were used for numerical simulations. The average monthly sales volume of this infant clothing is 99.5 pieces. Therefore, we set the basic market demand as $d = 100$. In addition, we set $\rho = 0.4$, $\beta = 0.6$, $\gamma = 0.5$ and $k = 0.4$.

6.1 Numerical Simulation of Decision Models

Let $\mu_2 = 0.5$. Therefore, we know from $k > k_1$ and $\mu_1 > \mu_2$ that the range of values of μ_1 is $0.5 < \mu_1 < 1$. Letting $\mu_1 \in (0.6,0.8)$, we can obtain Figure 1. Figure 1 shows the effect of μ_1 on equilibrium results under two decision models.

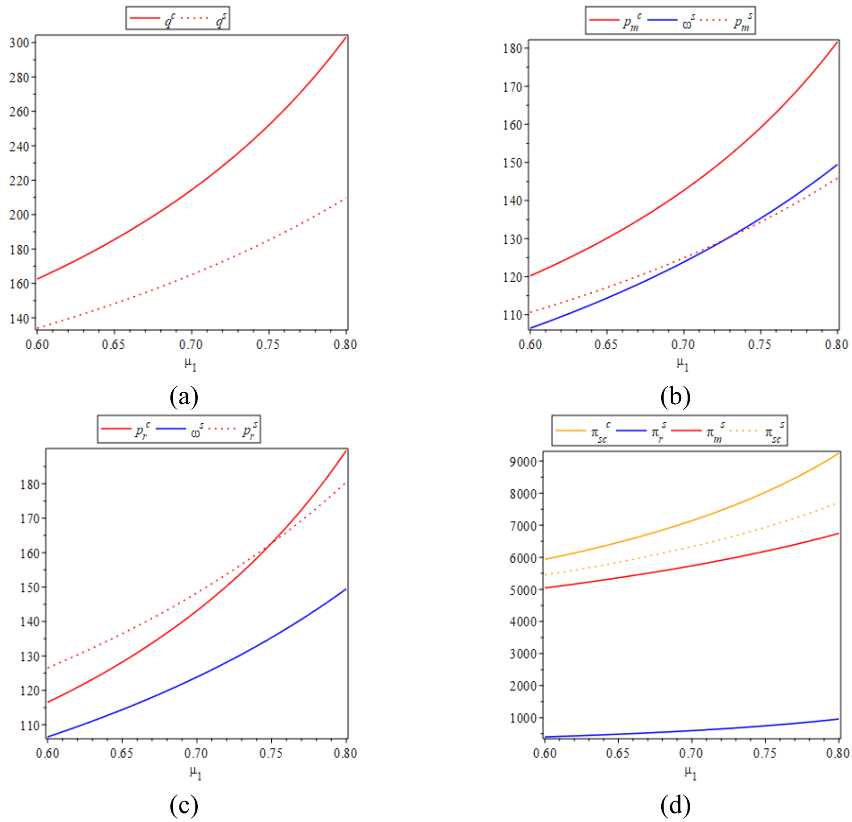


Figure 1. The effect of μ_1 on equilibrium results

Source: Authors' own creation.

In addition, let $\mu_1 = 0.6$. Therefore, we know from $k > k_1$ and $\mu_1 > \mu_2$ that the range of values of μ_2 is $0 < \mu_2 < 0.6$. Letting $\mu_2 \in (0.3,0.5)$, we can obtain Figure 2. Figure 2 shows the effect of μ_2 on equilibrium results under the two decision models.

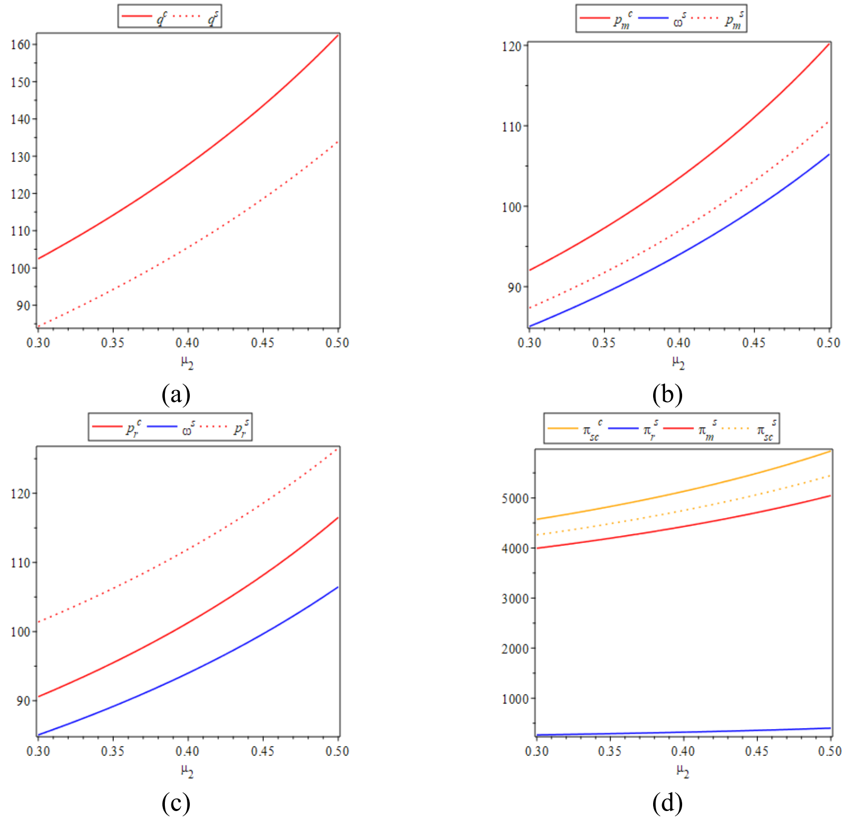


Figure 2. The effect of μ_2 on equilibrium results

Source: Authors' own creation.

We can find from Figure 1 that in centralised supply chain or decentralised supply chain, with the increase of the offline consumer's perception of quality, all decision variables and profits of all parties will increase. This is consistent with Corollaries 5 and 6. The improvement of the offline consumer's perception of quality can lead to higher quality products. The manufacturer and the retailer should take steps to improve the offline consumer's perception of quality. This also explains why salespeople always encourage consumers to try out the products. Because it will improve consumer perception of product quality.

We can find from Figure 2 that in centralised supply chain or decentralised supply chain, with the increase of the online consumer's perception of quality, all decision variables and profits of all parties will increase. This is consistent with Corollaries 5 and 6. As mentioned above, steps taken by the manufacturer and retailer to improve the online consumer's perception of quality will contribute to further profit growth for both parties.

Figure 1 (a) and Figure 2 (a) reveal that the quality level under the centralised supply chain is greater than that under the decentralised supply chain. This result is supported by Zhang et al. (2020) and Chen et al. (2017). This is consistent with Corollary 1. The centralised supply chain offers consumers a higher quality product. This is highly responsive to the growing sensitivity of consumers to quality.

Figure 1 (b) and Figure 2 (b) reveal that the online direct selling price under the centralised supply chain is higher than that under the decentralised supply chain. This result is supported by Liu et al. (2022) and Chen et al. (2017). This is consistent with Corollary 2. In the centralised supply chain, consumers could buy higher prices and higher quality products from the online channel. The manufacturer sets a higher direct selling price to cover the cost of quality improvement. Figure 1 (b) also shows that when the offline consumer's perception of quality is too large, the wholesale price is even higher than the online direct selling price. This is an interesting finding. At this point, the manufacturer should preferably wholesale all of the products to the retailer.

Figure 1 (c) shows that when $\mu_1 > 0.75$ ($k_1 < 0.4 < k_2$), the offline retail price under the centralised supply chain is greater than that under the decentralised supply chain. When $\mu_1 < 0.75$ ($k_2 < 0.4$), the result is reversed. Figure 2 (c) reveals that the offline retail price under the centralised supply chain is lower than that under the decentralised supply chain, when $k_2 < 0.4$. This is consistent with Corollary 3. This is an interesting finding. In a centralised supply chain, consumers buy products with higher quality but not necessarily higher price in the offline channel.

Figure 1 (d) and Figure 2 (d) reveal that the centralised supply chain profit is always greater than the decentralised supply chain profit. This result is supported by Liu et al. (2022), Chen et al. (2017), Xu et al. (2022) and Ranjan and Jha (2019). This is consistent with Corollary 4. In a centralised supply chain, both parties make decisions together. It eliminates price and channel competition among members. Moreover, in the decentralised supply chain, the manufacturer's profit is always higher than the retailer's profit. The reason is that the manufacturer has a first-mover advantage as leaders. From a supply chain perspective, it is more beneficial to supply chain profits when both parties make decisions together. This shows the necessity of coordinating the decentralised dual-channel supply chain to avoid profit loss.

6.2 Numerical Simulation of Coordination Contracts

Let $\mu_1 = 0.6$ and $\mu_2 = 0.5$. From $k > k_1$, we can obtain that the range of values of k is $k > 0.19$. Letting k take random values in the range of values, we can obtain Table 3. Table 3 represents the manufacturer's profit and retailer's profit under coordination contract 1 compared to those under the decentralised supply chain, and the overall profit under this contract compared to the centralised and decentralised supply chain profit.

From Table 3 we can obtain that under coordination contract 1, all supply chain members' profits are greater than those under the decentralised supply chain (${\pi_m}^{cp} > {\pi_m}^s$, ${\pi_r}^{cp} > {\pi_r}^s$), and the overall profit is the same as the centralised supply chain profit (${\pi_{sc}}^{cp} = {\pi_{sc}}^c > {\pi_{sc}}^s$). At this point, the dual-channel supply chain meets the conditions of coordination. The manufacturer and retailer receive a win-win scenario. Since the residual profit is allocated according to the cost payment of both parties in the decentralised supply chain, both parties can obtain a relatively fair profit from this contract. This contract is similar to the way in which China's state-owned enterprises share excess profits to incentivise employees based on their work.

Table 3. Comparison of profits under coordination contract 1

k	${\pi_m}^s$	${\pi_m}^{cp}$	${\pi_r}^s$	${\pi_r}^{cp}$	${\pi_{sc}}^s$	${\pi_{sc}}^{cp}$	${\pi_{sc}}^c$
0.19	24100.34	796440.97	12453.05	277273.32	36553.39	1073714.29	1073714.29
0.25	8824.08	10622.33	1458.77	2203.48	10282.85	12825.81	12825.81
0.30	6618.91	7345.95	761.67	1106.35	7380.58	8452.30	8452.30
0.35	5618.44	6051.88	519.44	751.04	6137.88	6802.92	6802.92
0.40	5047.27	5353.14	401.88	583.78	5449.15	5936.92	5936.92
0.45	4677.89	4914.44	333.87	488.86	5011.76	5403.30	5403.30
0.50	4419.42	4612.95	290.03	428.56	4709.45	5041.51	5041.51

Source: Authors' own creation.

Similarly, letting k take random values in the range of values, we can obtain Table 4.

Table 4. Comparison of profits under coordination contract 2

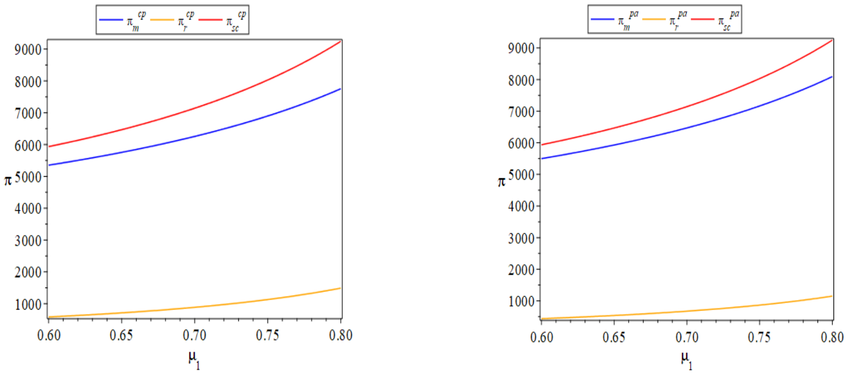
k	${\pi_m}^s$	${\pi_m}^{pa}$	${\pi_r}^s$	${\pi_r}^{pa}$	${\pi_{sc}}^s$	${\pi_{sc}}^{pa}$	${\pi_{sc}}^c$
0.19	24100.34	707920.15	12453.05	365794.14	36553.39	1073714.29	1073714.29
0.25	8824.08	11006.29	1458.77	1819.52	10282.85	12825.81	12825.81
0.30	6618.91	7580.03	761.67	872.27	7380.58	8452.30	8452.30
0.35	5618.44	6227.20	519.44	575.72	6137.88	6802.92	6802.92
0.40	5047.27	5499.07	401.88	437.85	5449.15	5936.92	5936.92
0.45	4677.89	5043.34	333.87	359.96	5011.76	5403.30	5403.30
0.50	4419.42	4731.03	290.03	310.48	4709.45	5041.51	5041.51

Source: Authors' own creation.

From Table 4 we can obtain that under coordination contract 2, ${\pi_m}^{pa} > {\pi_m}^s$, ${\pi_r}^{pa} > {\pi_r}^s$, and ${\pi_{sc}}^{pa} = {\pi_{sc}}^c > {\pi_{sc}}^s$. In the same way, the dual-channel supply chain is coordinated. Since the residual profit is allocated according to the profit allocation of both parties in the decentralised supply chain, both parties can obtain a relatively fair profit from this contract.

6.3 Additional Sensitivity Analysis

Under these two contracts, what impact will the consumer's perception of quality on the profits of all parties? Additional sensitivity analysis was performed to answer this question. Let $\mu_2 = 0.5$ and $\mu_1 \in (0.6,0.8)$. Figure 3 can be obtained.

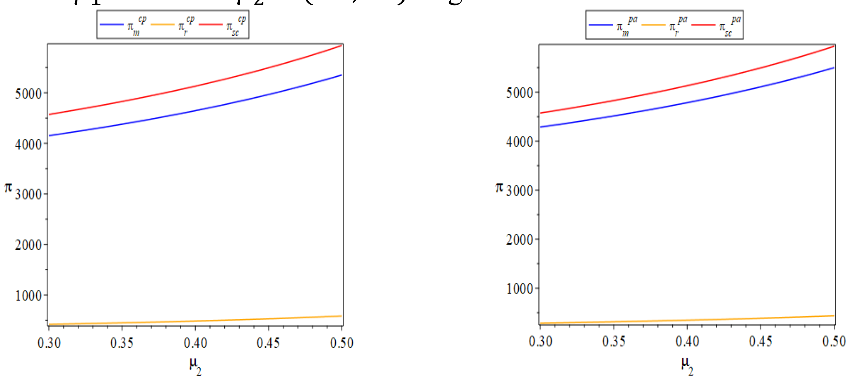


(a) (b)

Figure 3. Impact of μ_1 on profits under two contracts

Source: Authors' own creation.

Let $\mu_1 = 0.6$ and $\mu_2 \in (0.3,0.5)$. Figure 4 can be obtained.



(a) (b)

Figure 4. Impact of μ_2 on profits under two contracts

Source: Authors' own creation.

In Figure 3 and Figure 4, it is revealed that as the both offline and online consumer's perception of quality increases, the profits of all parties increase under two contracts. The improvement of quality perception drives the improvement of consumer demand, which, in turn, drives the improvement in all parties' profits. Through the application of these two contracts, the manufacturer and retailer should not only collaborate to make decisions, but also collaborate to improve the consumer's perception of quality. This will contribute to the further growth of profits for both parties.

7. Conclusions

Based on the fact that consumers have different perceptions of quality in the two channels, this paper investigates the dual-channel supply chain decisions and coordination problems. The conclusions are as follows. (1) Compared to the decentralised supply chain, the centralised supply chain can provide consumers with products of higher quality and obtain more profits. (2) Regardless of the centralised or decentralised supply chain, the online or offline consumer's perception of product quality will positively affect the decision variables and the profits of all parties. (3) Coordination contract 1 can coordinate the dual-channel supply chain. The manufacturer and retailer receive a relatively fair profit from the contract according to the proportion of the decentralised supply chain cost payment. (4) Coordination contract 2 can also coordinate the dual-channel supply chain. The manufacturer and retailer receive a relatively fair profit from the contract according to the proportion of the decentralised supply chain profit allocation. (5) The improvement of the consumer's perception of quality will cause the improvement of members' profits under these two coordination contracts.

In summary, we can provide the following management implications for manufacturers and retailers.

(1) For manufacturers: In the uncoordinated dual-channel supply chain, manufacturers could quantify the model parameters to make optimal decisions and gain profits according to the decision model results. Manufacturers should strive to improve the consumer's perception of product quality. The manufacturer can apply coordination contract 1 or coordination contract 2 to achieve dual-channel supply chain coordination. When using the contracts, manufacturers also can take actions, such as placing product advertisements, publishing product test results, and adding pre-buy free trials of products, to improve the consumer's perception of quality and further expand their own profits.

(2) For retailers: In the uncoordinated dual-channel supply chain, retailers also could quantify the model parameters to make optimal decisions and gain profits based on the decision model results. Retailers can boost their profits by actively raising the consumer's perception of product quality. Retailers should aggressively pursue cooperation with manufacturers to achieve coordination by applying these two contracts. When using the contracts, retailers can take action, such as investing more in advertising, providing excellent service, enhancing the product packaging visual experience of consumers, and offering random shopping surprises to consumers, to improve the consumer's perception of quality and further expand profits.

Although this study obtained some meaningful results, there are certain limitations. The dual-channel supply chain we studied does not recycle products. In reality, more and more manufacturers and retailers are engaging in the recycling business. The quality perception of recyclables by consumers is an important factor influencing consumer participation in recycling. Therefore, future research could study the impact of the consumer's perception of recycled product quality on the dual-channel closed-loop supply chain.

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